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Indian Standard

METHOD OF MEASUREMENT OF FLOW OF WATER IN OPEN CHANNELS USING STANDING WAVE FLUME-FALL

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METHOD OF MEASUREMENT OF FLOW OF WATER IN OPEN CHANNELS USING STANDING WAVE FLUME-FALL

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METHOD OF MEASUREMENT OF FLOW OF WATER IN OPEN CHANNELS USING STANDING WAVE FLUME-FALL

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 16 March 1971, after the draft finalized by the Fluid Flow Measurement Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Similar to the standing wave flumes, standing wave flume-falls have their application in the measurement of discharge in artificial channels, such as irrigation canals. The standing wave flume-fall can be depended upon to perform satisfactorily as a useful flow measuring device. Its chief merit lies in having only one gauge observation on the upstream as compared to venturi flumes which require two gauge observations and also in its constancy of modularity relationship even with the sediment deposition in the upstream side.

0.3 Generally, standing wave flumes should be used. Standing wave flume-falls are used as necessitated by topography (when there is appreciable fall in water level) for efficient dissipation of energy downstream.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard covers the use of standing wave flume-falls, as described subsequently, for the measurement of flow of water in open channels. The flow conditions considered are limited to steady flows which are uniquely dependent on the upstream head. The submerged flows beyond modular limits which depend on downstream as well as upstream water levels are not considered.

*Rules for rounding off numerical values (revised).

1.2 An example is given in Appendix A to provide guidelines for the designer.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 1191-1959* and the following shall apply.

2.1 **Baffle** — A wall built across a flume at downstream edge of baffle platform.

2.2 **Cistern** — A pool of water maintained to take the impact of water flowing down a flume.

2.3 **Deflector** — A wall of suitable height built across the pavement at the end of the cistern to ensure the formation of a positive bed roller (a bed roller which will not cause retrogression of levels towards toe) immediately downstream.

2.4 **Fluming Ratio** — It is the ratio of bed width of flume at contracted section (including piers) to the bed width of the channel upstream.

2.5 **Glacis** — The sloping floor below and in continuation of the raised crest of a flume.

2.6 **Hurdling** — Water flowing over the top of a baffle with a high velocity like horse taking on a fence.

2.7 **Surging** — Surging occurs when the downstream water level is too high and the secondary wave downstream of baffle is drowned.

3. INSTALLATION

3.1 **Selection of Site** — A preliminary survey should be made of physical and hydraulic features of the proposed site to check that it conforms (or may be made to conform) to the requirements necessary for measurements by standing wave flume-falls. Particular attention should be paid to the following features in the selection of site:

- a) Availability of adequate length of straight channels;
- b) Reasonably symmetrical and regular velocity distribution,
- c) Avoidance of supercritical flow immediately upstream;
- d) Rise in upstream water levels due to the measuring structure; and
- e) Absence of conditions downstream of standing wave flume-falls which may affect working, by drowning, such as by a controlling structure.

*Glossary of terms used in the measurement of flow of water in open channels (*under revision*).

If the site does not possess the characteristics (a), (b) and (c) which are necessary for satisfactory measuring, it should be rejected unless suitable improvements are practicable. If an inspection of the channel shows that existing velocity distribution is regular then it may be assumed that the velocity distribution will remain satisfactory after the construction of the standing wave flume-fall.

If the existing velocity distribution is irregular and no other site is feasible, due consideration should be given to the checking of distribution after the installation of standing wave flume-fall and to improve it, if necessary. A complete and quantitative assessment of velocity distribution may be made by means of a current meter. Complete information about the use of current meter is given in IS : 3918-1966*.

3.2 Installation Conditions

3.2.1 General — The complete measuring installation consists of an approach channel, a measuring structure (standing wave flume-fall) and a downstream channel. The condition of each of these three components affects the overall accuracy of the measurement (see 3.2.2, 3.2.3 and 3.2.4).

Installation requirements include such features as precise dimensions of structure, its finish, regular cross-sectional shape of approach and exit channels, influence of control devices upstream and downstream of structures, etc.

Once an installation has been designed, any change which would affect the basis of design should be prevented.

3.2.2 Approach Channel — On all installations the flow in the approach channel shall be smooth, free from disturbance and have velocity distribution as normal as possible over the cross-sectional area. This may be usually verified by measurements. Unless otherwise specified in the appropriate sections, the following general requirements shall be complied with:

- a) The altered flow conditions due to the construction of standing wave flume-fall might have the effect of deposition of sediment upstream of the structure. The likely consequential changes in the water level should be taken into account in the design.
- b) The natural stream or river cross-section should be reasonably uniform and the channel should be straight for such a length as to ensure uniform velocity distribution. If the entry to the approach channel is through a bend or if the flow is discharged into the channel from head regulator through a conduit of smaller

*Code of practice for use of current meter (cup type) for water flow measurement,

cross-sectional area or at an angle, then a longer length of straight approach channel may be required to achieve an even velocity distribution.

- c) The channel should be in overall regime, that is, over the year there are inappreciable changes

3.2.3 The Measuring Structure (Standing Wave Flume-Fall) — The standing wave flume-fall consists of an approach transition, a throat with or without hump, exit transition, a baffle and baffle platform (between the glacis and cistern) for better dissipation of energy and the exit may have either parallel sides or expanding sides (see Fig. 1). The entire measuring structure shall be rigid and watertight, at least, for a length L_4 shown in Fig. 1. It should be at right angles to the general direction of flow and conform to the dimensions given in relevant clauses

3.2.4 Downstream Channel — The channel downstream of the measuring structure (standing wave flume-fall) is usually of little importance, as such, provided that the standing wave flume-fall has been so designed that it cannot become drowned under operating conditions due to silting, back water effects, etc. The effect of rise in the water level on the downstream due to silting would normally be immaterial, as far as rating of the standing wave flume-fall is concerned.

3.2.4.1 The altered flow conditions due to construction of the measuring structure (standing wave flume-fall) might have an effect of building shoals of sediment downstream of the structure, which in course of time might raise the water level sufficiently to cause submergence of flow. Any accumulation of sediment downstream of the structure should, therefore, be removed from time to time.

4. MAINTENANCE

4.1 Maintenance of the measuring structure (standing wave flume-fall) and approach channel is important to secure accurate continuous measurements. It is essential that approach channel be kept clean and free from vegetation and sediment as far as practicable for at least the distance specified in 3.2.2(b). The float or gauge (stilling) well and the connection to it from the approach channel shall also be kept clean and free from deposits. The measuring structure shall be kept clean and free from clinging sediment and care shall be taken in the process of cleaning to avoid damage to the structure. To ensure proper maintenance, periodic inspection at suitable intervals should be made.

5. MEASUREMENT OF HEAD

5.1 General — The water level upstream of the standing wave flume-fall may be measured by any suitable type of a gauge where only spot

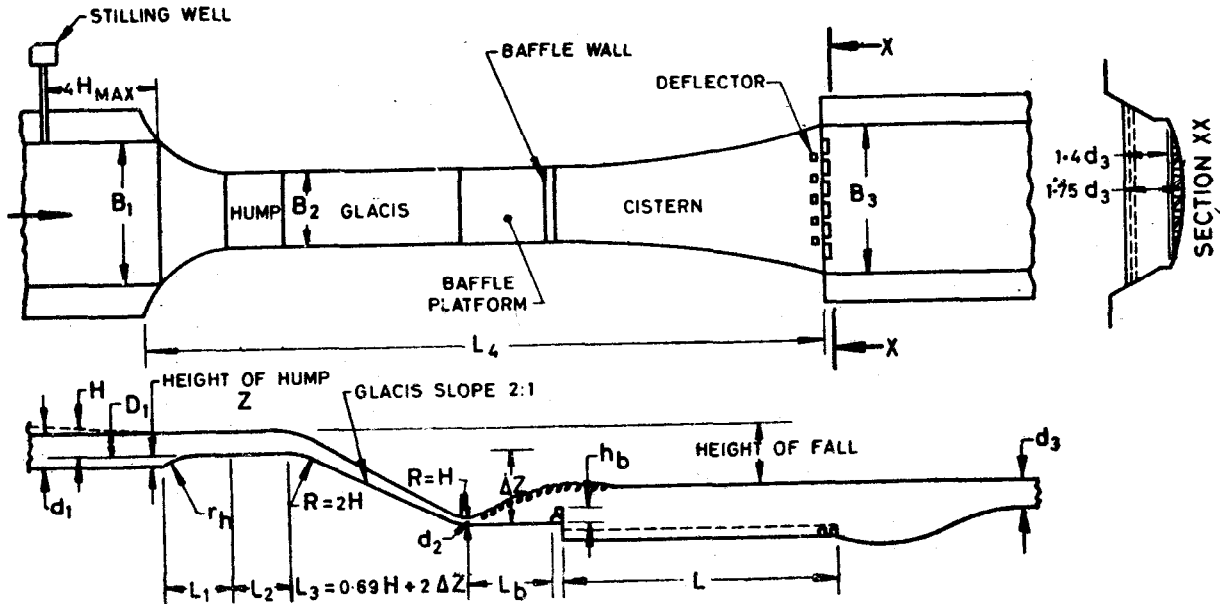


FIG. 1 DETAILS OF A STANDING WAVE FLUME-FALL

measurements are required, and with an automatic recording type of gauge where continuous record is required. Gauge observation should, however, invariably be made so that fluctuations are damped down, such as in a stilling well to reduce surface irregularities.

5.2 Gauge (Stilling) Well — The stilling well should be so located as to measure the water level upstream of the sill where there is no curvature of flow. This could be ensured by locating the stilling well intake pipe at a distance of $4 H_{max}$, upstream of the bell mouth entrance where H_{max} is the maximum value of upstream head over the sill corrected for the velocity of approach.

5.2.1 The stilling well should be normally vertical and have a minimum margin of at least 15 cm over the maximum water level estimated to be recorded in the well. The stilling well should either be carried on a solid foundation slab below the bottom of the well, or when pipe construction is adopted the well pipe may be hung from an under-floor located below the point where the pipe emerges from the bank. The under-floor should extend well beyond the limit of the intake pipe trench on both sides and should be solidly bedded on undisturbed ground. The well dimensions should be large enough (say 60×90 cm) to permit the bottom of the well to be cleaned. The smallest dimension of the well should be, however, not less than twice the diameter of the float of the recorder as given in the Draft 'Indian Standard specification for water stage recorders (float type)' (*under preparation**). It is an advantage to fit more than one intake pipe to the well, the lowest being situated below the lowest anticipated stage of flow and the others at suitable levels below normal water level. In this way, if during the season of high water the lower pipe(s) becomes obstructed and it is not possible to clean it (them) owing to the depth of water, the recorder will continue to operate on the upper intake(s) until the water level falls sufficiently to allow access to the lower pipe(s). The upper pipes will be usually accessible for cleaning. It is convenient to provide valves in the intake pipes and install flushing systems to clear sediment from the pipes and if this arrangement is impracticable, means for cleaning with flexible sewer rods should be provided. Further, silt trap may be provided near the end of the intake pipe where it takes off from the channel in order to retard silting.

5.2.1.1 The diameter of the intake pipe should generally be 10 cm. If larger pipes or an open intake is used, a valve or penstock should be fitted to control surge in the well. Intake pipes should be laid level throughout their length; if they exceed 20 m in length an intermediate inspection man-hole should be constructed. The bottom of the well should

*Until the standard under preparation is published the matter shall be subject to agreement between the concerned parties.

be carried at least about 30 cm below the level of the lowest intake pipe so that there may be no danger of the float grounding when the stream falls to its minimum level.

5.3 Zero Setting — Means of checking the zero setting of head measuring device should be provided, consisting of a pointer with its points set exactly level with the sill of standing wave flume-fall and fixed permanently in the approach channel or alternatively in the stilling or gauge well, wherever provided. The zero setting should be periodically checked.

5.3.1 A checking for zero setting based on the level of water when the flow ceases, is liable to serious errors from the surface tension effects and should not be used. As the size of standing wave flume-fall and head on it reduces, small errors in construction, in zero setting and reading of head measuring device become more and more important.

5.4 Head Loss — This consists of the following losses:

- a) Approach transition,
- b) Exit transition,
- c) Friction in the structure, and
- d) Hydraulic jump.

5.4.1 Loss in approach and exit transitions depend on the amount of fluming and its gradualness. These are expressed as a fraction C of the difference in velocity head of flow in the channel and the standing wave flume-fall. These are usually taken as 0.15 for the approach transition of cylinder quadrant type and 0.3 for exit transition with splay of 1 in 10 and 0.2 with hyperbolic type.

Loss in friction is usually small. It may be of the order of 0.015 to 0.03 m depending upon the size and the critical velocity.

Loss in a hydraulic jump H_L is given by:

$$H_L = \frac{(d'' - d')^3}{4 d' d''} \quad \dots \dots \dots (1)$$

where

d' = depth before jump, and

d'' = depth after jump.

6. SPECIFICATION FOR STANDING WAVE FLUME-FALL

6.0 The entire measuring structure shall be finished with smooth and true surfaces (in this specification smooth surface shall correspond to a neat

cement finish). The intersection of upstream curve and hump as well as the downstream slope shall form two parallel straight lines at right angles to the direction of flow.

6.1 Approach Transition (Bell Mouth Entrance)

6.1.1 Side Contractions — The radius of side walls of the bell mouth entrance should be $3.6 H^{1.5}$ m, where H is the upstream head above the sill level of throat corrected for velocity of approach. But when H is less than 0.3 m the radius may be $2H$ from the throat. The curvature should continue till it subtends an angle of 60° from where it should be continued tangentially to meet the side of the channel upstream. For smaller head loss the radius of curvature should be increased to $4.5 H^{1.5}$ m. This curvature should continue till it subtends an angle of $37^\circ 30'$ beyond which the wall should be continued straight to meet the sides of the approach channel. The bed convergence should begin on the same cross-section as the side convergence. The radius of curvature of the hump in the bed should be:

$$r_h = \frac{L_1^2 + Z^2}{2Z} \quad \dots \dots \dots (2)$$

where

r_h = the radius of curvature of the hump,

L_1 = length between the junction of the side wall with the bed of the upstream channel and upstream end of the throat measured along the axis, and

Z = height of hump above upstream bed of the channel.

When the total head above the sill of the flumed standing wave fall becomes considerable, say, 1.2 m, the height of hump Z becomes insignificant as compared to L_1 as that the radius becomes large and the upstream end of the throat may be joined by a straight line to the channel bed upstream.

6.2 Throat — Sides of throat should be vertical and length should be $2.5 H$, where H is the upstream head above the sill level of the throat corrected for velocity of approach. Width of the throat may be calculated by the formula given in 7.1.

6.2.1 Too great a constriction, however, causes more head loss. Width should not, therefore, be kept less than $1.5 H$. Where head loss provided in the design is not adequate, fluming should normally be restricted to 50 to 60 percent.

6.3 Hump—The stage discharge relation of a canal or distributory is given by:

$$Q = C_1 d_1^x \quad \dots \dots \dots (3)$$

where

Q = discharge,

C_1 = a coefficient,

d_1 = depth of water in the channel, and

x = the index varying from 1.5 to 2.

6.3.1 Values of x are summarized in Table 1.

TABLE 1 VALUES OF x

SL No.	SHAPE OF CHANNEL	x
i)	Rectangular	1.5
ii)	Trapezoidal	Variable and increases with the flatness of the side slope
iii)	Unlined canals with design side slopes $\frac{1}{2}$ to 1	1.6 to 1.7
iv)	Lined canals with slopes $1\frac{1}{2}$ to 1	1.9 to 2

As compared to the equation in 6.3, in case of a broad crested weir Q is proportional to $H^{1.5}$, where H is head upstream over sill of throat corrected for velocity of approach. As the exponent of d_1 is greater than the exponent of H , there will be drawdown at low supplies and ponding near full supply levels provided the sill of the throat is at the same level of the channel bed. This can be avoided by providing a hump in the throat. The height of hump Z required to give proportionality, that is, rate of change in d_1 equal to the rate of change in D_1 at a particular discharge is given by:

$$Z = d_1 - D_1 = d_1 \left\{ m^{1/x} - \frac{3m^{2/3}}{2x} \right\} \quad \dots \dots \dots (4)$$

where

D_1 = the depth upstream over the sill of throat, and

m = any particular fraction of discharge

The height of hump required to give proportionality for a small variation in discharge will thus vary according to the magnitude of the discharge. Figure 2 gives the height of hump required for various values of m and x .

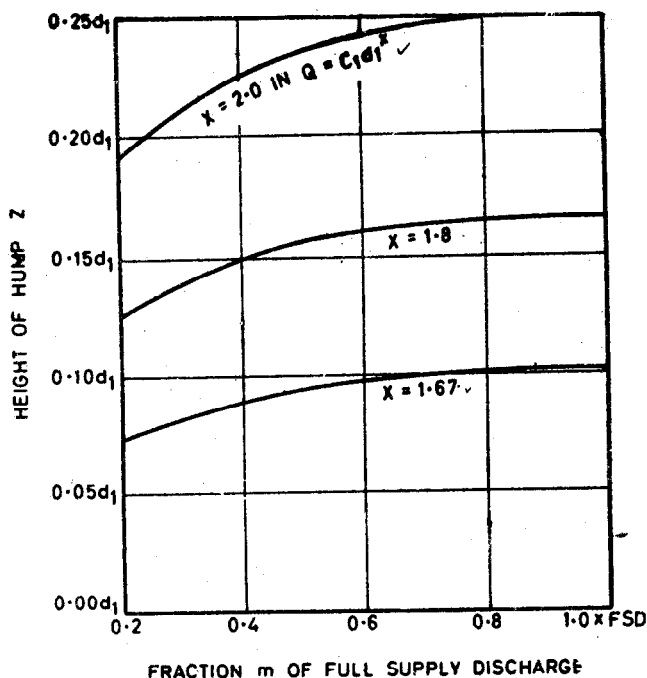


FIG. 2 HEIGHT OF HUMPS REQUIRED TO GIVE PROPORTIONALITY FOR A SMALL VARIATION IN DISCHARGE

6.3.2 Where channels are run with fluctuating discharge, the proportionality is not obtainable for the whole range and it is then desirable to design the hump such that the error over the range of discharges chosen will be minimum. This is called the bulk proportionality and in this case the height of hump required is given by:

$$Z = d_1 - D_1 = d_1 m^{1/n} \left\{ 1 - \left(\frac{\frac{1}{m^{1/\infty}} - 1}{\frac{1}{m^{2/3}} - 1} \right) \right\} \quad \dots \dots (5)$$

NOTE — In case of canals run either full or closed, it is desirable to have a standing wave flume-fall which gives proportionality at a full supply discharge. In case of channels in which discharge varies considerably bulk proportionality is preferable.

Figure 3 gives the height of hump required for various values of x and fluctuations in discharges.

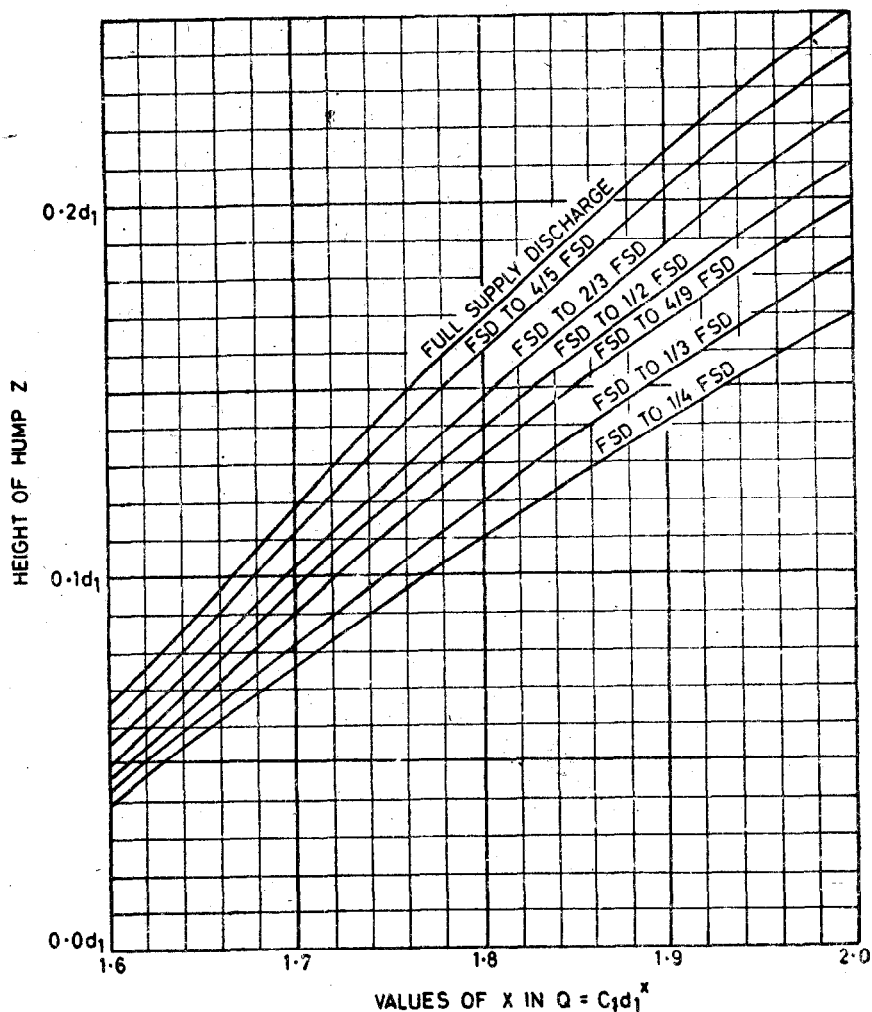


FIG. 3 HEIGHT OF HUMP TO ATTAIN BULK PROPORTIONALITY

6.4 Glacis — Glacis slope should be equal to 2 : 1 connected with the throat by a curve of radius equal to $2 H$ tangential to glacis and sill of flume. The downstream edge of glacis should also be connected with baffle platform by a curve of radius equal to H (see Fig. 1), tangential to glacis and the baffle platform. The axial length of the glacis including curved portion should be equal to $0.69 H + 2 \Delta Z$

where

ΔZ = the difference of level in the crest and the baffle platform.

6.5 Baffle Platform — The baffle platform should be fixed at such a level that a standing wave shall form at the toe of the glacis. If the platform is too high, then hurdling will occur. On the other hand, if platform is too low, surging will take place. In case of a fall with parallel sides, the level of baffle platform may be estimated by the following procedure:

The depths of water d_5 above baffle platform in a parallel sided fall is first calculated with the following equations:

$$d_5 = \frac{-d_2}{2} + \left[\frac{2q^2}{gd_2} + \frac{d_2^2}{4} \right]^{\frac{1}{2}} \quad \dots \dots (6)$$

$$\frac{q}{d_2} = C_f \left[2g (H + \Delta Z - d_s) \right]^{\frac{1}{2}} \quad \dots \dots (7)$$

where

d_2 = the supercritical flow depth at the toe of glacis immediately upstream of jump,

q = the discharge per unit width,

g = acceleration due to gravity, and

C_f = the coefficient for friction (see 7).

Level of baffle platform is assumed which would give d_5 and ΔZ . Substituting the value of ΔZ in equation 7, d_2 is worked out. This in turn gives value of d_5 by equation 6. If assumed value does not tally with the one worked out as above, more trials would be needed. The level of baffle platform is then obtained by deducting d_5 from downstream water level.

In case of a fall with expanding sides, the fall in water level ΔZ_e is first required to be converted into ΔZ_p which is the fall in water level with parallel sides, by using the following equation:

$$\Delta Z_e = \frac{\Delta Z_p}{K^{0.152}} \quad \dots \dots (8)$$

where

K = the flumming ratio = $\frac{B_2}{B_1}$ (see Fig. 1).

The d_s is then estimated by trial and error procedure as given above. With known ΔZ_e , ΔZ_p and d_s , the value of d_4 which is the depth of water above baffle platform in case of a fall with expanding sides may be worked out using equation:

$$\Delta Z_e + d_4 = \Delta Z_p + d_s \quad \dots \dots \dots (9)$$

To ensure that the standing wave will form at the toe of the glacis a baffle should be provided at the end of baffle platform. The height of the baffle (h_b) is given by:

$$h_b = 1.5 (D_c - d_s) \quad \dots \dots \dots (10)$$

where

D_c = the critical depth of flow above sill of flume at the controlling section, that is $\left(\frac{q^2}{g}\right)^{\frac{1}{3}}$

The distance of baffle from the toe of the glacis should be equal to 5.25 h_b . If the baffle is fixed near to the toe of glacis then water with supercritical velocity would hurdle over the baffle without forming primary or secondary wave and energy will not be dissipated efficiently. The upstream face of baffle should be curved with radius equal to and ending at $\frac{2}{3}$ of the h_b .

6.6 Expansion — Sides downstream of baffle platform should be curved with hyperbolic expansion to ensure uniform distribution of flow downstream. The equation of hyperbola may be:

$$B_y = \frac{B_0 E_s L}{L B_s - (B_s - B_0) y} \quad \dots \dots \dots (11)$$

where

B_y = width at any distance y ;

y = distance from beginning of expansion of hyperbola;

B_0 = overall throat width including piers, if provided. If not, B_0 becomes B_s the width of flume at the contracted section (excluding piers);

B_s = bed width of downstream channel; and

L = length of cistern (see 6.7).

6.7 Cistern — Depth of cistern at sides below downstream water level should be 1.4 d_s and in the middle 1.75 d_s , where d_s is the depth of water in the channel downstream. The bed of cistern at the sides should not be higher than the bed of channel downstream.

The recommended length of cistern for different soils have been given below:

$$L = \begin{cases} 6 d_3 & \text{in shingle bed} \\ 7.5 d_3 & \text{in good earth} \\ 9 d_3 & \text{in coherent sand} \end{cases}$$

The cistern should be horizontal in longitudinal profile.

6.8 Deflectors — At the downstream end of cistern a deflector of the following dimensions should be constructed to ensure the formation of a positive bed roller:

Height of deflector should be equal to one-twelfth the depth of water in midstream. Gaps in the deflector should be equal to height of deflector and at intervals of 4 times the height with short walls placed close to the upstream of gaps to prevent jetting of water (see Fig. 4).

7. COMPUTATION OF DISCHARGE

7.1 The discharge equation for a standing wave flume-fall is given by:

$$Q = \frac{2}{3} \sqrt{2g} C_f (B_0 - mb - 2C_c mH) H^{1.5} \quad \dots \quad (12)$$

where

Q = discharge,

g = gravitational acceleration,

C_f = coefficient for friction having the following values:

0.97 for $Q = 0.05$ to $0.3 \text{ m}^3/\text{s}$

0.98 for $Q = 0.3$ to $1.5 \text{ m}^3/\text{s}$

0.99 for $Q = 1.5$ to $15 \text{ m}^3/\text{s}$

1.00 for $Q = 15 \text{ m}^3/\text{s}$ and above,

B_0 = overall throat width including piers,

m = number of piers,

b = thickness of each pier,

C_c = coefficient of contraction having a value 0.045 for piers with round nose and 0.040 for piers with pointed nose, and

$H = D_1 + h_v$ = upstream head over sill corrected for velocity of approach

$$= D_1 + \frac{\bar{v}_a^2}{15.2}$$

D_1 = the depth upstream over sill of throat, and

$\bar{v}_a$ = the mean velocity of approach.

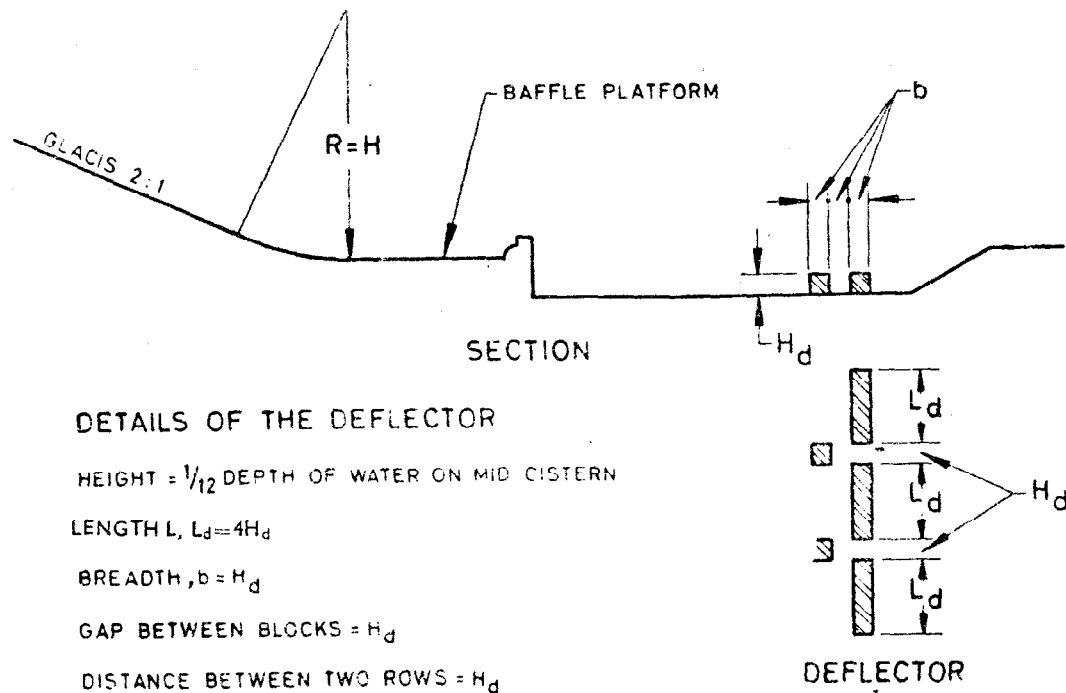


FIG. 4 DETAILS OF THE DEFLECTOR IN THE CISTERN

Effect of velocity of approach is greater than $\frac{v_a^3}{2g}$ because the velocity in the central portion is higher than $\bar{v}_a$. Therefore, the head due to velocity of approach should be taken as

$$h_v = \frac{\bar{v}_a^3}{15.2}$$

8. ACCURACY OF MEASUREMENT

8.1 The overall accuracy of measurement will depend on:

- the proper selection of site, in particular the characteristics (a), (b) and (c) given in 3.1 are satisfied;
- the correct observance of the installation conditions; and
- the accuracy of zero setting and head measurements.

8.2 With skill and care in the construction of the measuring structure (standing wave flume-fall), the basic equations and the coefficients are expected to give accurate results. Studies to determine errors are being made.

9. LIMITATIONS

9.1 For satisfactory functioning of the standing wave flume-fall the ratio D_2/D_1 should be less than 0.5 (see Fig. 5) where

D_1 = depth upstream over the sill of throat, and

D_2 = depth downstream above sill of throat.

For D_2/D_1 greater than 0.5 standing wave flumes may be used.

APPENDIX A

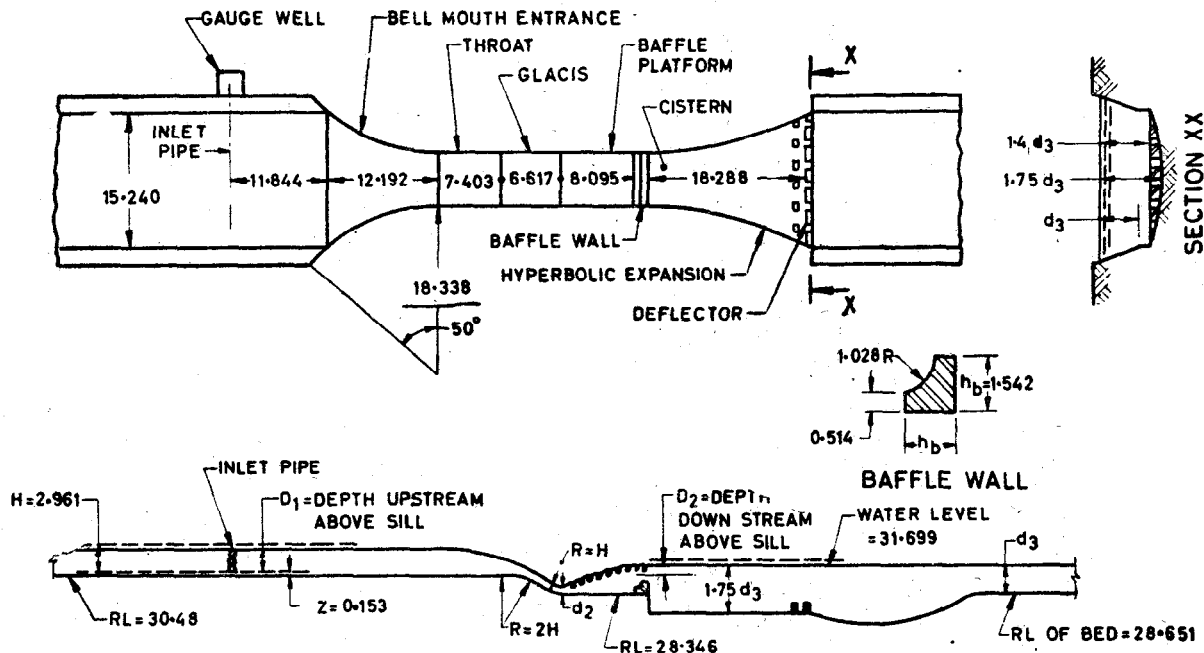
(Clause 1.2)

A TYPICAL DESIGN OF STANDING WAVE FLUME-FALL

A-1. CRITERIA OF DESIGN

A-1.1 The following conditions have to be satisfied while designing a standing wave flume-fall:

- The standing wave flume-fall should work for bulk proportionality between full supply discharge (FSD) and $1/3$ full supply discharge ($1/3$ FSD), and
- The fall should be designed with hyperbolic expansion in the cistern.



NOTE 1 — Total Discharge (Q) = 15.352 m³/s

NOTE 2 — Fall in Water Surface = 1.829 m

NOTE 3 — $\frac{D_2}{D_1} = \frac{1.066 \text{ m}}{2.895 \text{ m}} = 0.3680 < 0.5$

All dimensions in metres.

FIG. 5 TYPICAL DESIGN OF A STANDING WAVE FLUME-FALL

A-2. DATA GIVEN**A-2.1** Details are as given below:

Bed width of canal (B_1 and B_3)	15.240 m
Side slope of canal	$\frac{1}{2} : 1$
Bed slope of canal	1 : 6000
Manning 'n' for canal	0.022 5
Full supply depth in canal (d_1 and d_3)	3.048 m
Full supply discharge	51.352 m ³ /s
Fall in water level = fall in bed level = ΔZ_e	1.829 m
Bed level of canal on the upstream	30.480 m

A-3. DESIGN**A-3.1** Details of design are as given below:

a) *Height of Hump*—Hump height is designed in accordance with 6.3. In order to estimate the height of hump for bulk proportionality, it is necessary to establish stage discharge relationship of canal which is given by $Q = c_1 d_1^x = c_1 d_3^y$.

Hence, the discharges of the canal for various depths are first estimated.

$$\therefore \text{For } d_1 = 3.048 \text{ m}$$

$$\begin{aligned} \text{Area} = A &= (b_1 + 0.5 \times d_1) d_1 = (15.240 + 0.5 \times 3.048) 3.048 \\ &= 51.097 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Perimeter} = P &= b_1 + 2 \times d_1 \times \sqrt{1^2 + 0.5^2} = b_1 + 2.236 d_1 \\ &= 15.240 + 2.236 \times 3.048 = 22.055 \text{ m} \end{aligned}$$

$$R_h = A/P = \frac{51.097}{22.055} = 2.317 \text{ m}$$

$$\text{Velocity} = V = \frac{1}{0.0225} \times \frac{2.317^{\frac{2}{3}}}{(6000)^{\frac{1}{3}}} = 1.005 \text{ m/s}$$

$$\text{Discharge} = Q = A \times V = 51.097 \times 1.005 = 51.352 \text{ m}^3/\text{s}$$

Adopting smaller depths than d_1 as d'_1 , d''_1 , d'''_1 , etc,

$$\text{For } d'_1 = 2.438 \text{ m}$$

$$\begin{aligned} A' &= (b_1 + 0.5 d'_1) \times d'_1 = (15.240 + 0.5 \times 2.438) \times 2.438 \\ &= 40.127 \text{ m}^2 \end{aligned}$$

$$P' = b_1 + 2.236 d'_1 = 15.240 + 2.236 \times 2.438 = 20.691 \text{ m}$$

$$R'_h = A'/P' = \frac{40.127}{20.691} = 1.939 \text{ m}$$

$$V' = \frac{1}{0.0225} \times \frac{1.939^{\frac{3}{2}}}{(6000)^{\frac{1}{2}}} = 0.892 \text{ m/s}$$

$$Q' = A' \times V' = 40.127 \times 0.892 = 35.793 \text{ m}^3/\text{s}$$

$$\text{For } d''_1 = 1.829 \text{ m}$$

$$\begin{aligned} \text{Area} = A'' &= (b_1 + 0.5 d''_1) \times d''_1 \\ &= (15.240 + 0.5 \times 1.829) \times 1.829 = 29.546 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} P'' &= b_1 + 2.236 d''_1 = 15.240 + 2.236 \times 1.829 \\ &= 19.330 \text{ m} \end{aligned}$$

$$R''_h = A''/P'' = \frac{29.546}{19.330} = 1.529 \text{ m}$$

$$V'' = \frac{1}{0.0225} \times \frac{1.529^{\frac{3}{2}}}{(6000)^{\frac{1}{2}}} = 0.761 \text{ m/s}$$

$$Q'' = A'' \times V'' = 29.546 \times 0.761 = 22.485 \text{ m}^3/\text{s}$$

$$\text{For } d'''_1 = 1.524 \text{ m}$$

$$\begin{aligned} \text{Area} = A''' &= (b_1 + 0.5 d'''_1) \times d'''_1 = (15.240 + \\ &\quad 0.5 \times 1.524) \times 1.524 = 24.387 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} P''' &= b_1 + 2.236 d'''_1 = 15.240 + 2.236 \times 1.524 \\ &= 18.648 \text{ m} \end{aligned}$$

$$R'''_h = A'''/P''' = \frac{24.387}{18.648} = 1.308 \text{ m}$$

$$V''' = \frac{1}{0.0225} \times \frac{1.308^{\frac{3}{2}}}{(6000)^{\frac{1}{2}}} = 0.686 \text{ m/s}$$

$$Q''' = A''' \times V''' = 24.387 \times 0.686 = 16.729 \text{ m}^3/\text{s}$$

From the above sets of discharges Q, Q', Q'', Q''' , etc, for the flow depths of d_1, d'_1, d''_1, d'''_1 , etc, respectively, the x in the equation $Q = c_1 d_1^x$ is estimated by least square method as given below:

$$x = \frac{\sum \log Q \cdot \log d_1 - \frac{(\sum \log Q)(\sum \log d_1)}{M}}{\sum (\log d_1)^2 - \frac{(\sum \log d_1)^2}{M}}$$

where

M = the number of sets, which is 4 in present case

$$\therefore x = 1.615, \text{ say, } 1.62.$$

The height of hump would be estimated for bulk proportionality from Q to Q'' , that is, from FSD to about $1/3$ FSD.

Hence from the graph in Fig. 3, or from equation (5), height of hump Z is $0.05 d_1 = 0.05 \times 3.048 = 0.1524$ m, say, 0.153 m.

b) *Width of Throat* — Throat width is designed in accordance with 6.2. Specific energy over the sill = $H = D_1 + h_v = d_1 - Z + h_v$

$$= 3.048 - 0.153 + \frac{(1.005)^2}{15.2} = 2.961 \text{ m}$$

The discharge formula applicable is:

$$Q = \frac{2}{3} \sqrt{\frac{2}{3} g} \cdot C_f (B_0 - mb - 2 C_c mH) H^{1.5}$$

Since there are no piers in the flumed throat, above equation is simplified to $Q = \frac{2}{3} \sqrt{2g} \cdot C_f B_s \times H^{1.5}$ giving $B_s = \frac{Q}{\frac{2}{3} \sqrt{\frac{2}{3} g} \cdot C_f H^{1.5}}$

wherein

$$C_f = 1.00 \text{ given in 7.1.}$$

$$\text{Hence } B_s = \frac{51.352}{1.705 \times 1 \times 2.961^{1.5}} = 5.913 \text{ m}$$

1) *Verification of adequacy of width of throat* — According to 6.2, the width of throat should not be less than $1.5 H$.

$$\therefore \text{Minimum width required} = 1.5 \times 2.961 = 4.442 \text{ m}$$

$$\text{Width provided} = 5.913 \text{ m}$$

$\therefore$ Width of throat provided is adequate.

2) *Verification of drawdown and ponding for smaller discharge*

$$\text{For } Q' = \frac{2}{3} (\sqrt{\frac{2}{3} g}) C_f B_s H'^{1.5} = 35.793 \text{ m}^3/\text{s}$$

$$\therefore H'^{1.5} = \frac{35.793}{1.705 \times 5.913} = 3.550$$

$$\therefore H', \text{ that is, the required head} = 2.327 \text{ m}$$

$$\text{Corresponding actual head on sill} = d'_1 - Z + h'_v$$

$$= 2.438 - 0.153 + \frac{(0.892)^2}{15.2} = 2.337 \text{ m}$$

Comparing actual head with the required head, drawdown for Q is obtained as $2.337 - 2.327 = 0.010$ m.

Similarly for $Q'' = \frac{2}{3} (\sqrt{\frac{2}{3} g}) C_f B_2 H''^{1.5} = 22.485 \text{ m}^3/\text{s}$

$$\therefore H''^{1.5} = \frac{22.485}{1.705 \times 5.913} = 2.230$$

$\therefore H''$, that is, head required = 1.707 m

$$\begin{aligned} \text{Actual head on sill} &= d''_1 - Z + h''_v = 1.829 - 0.153 + \frac{(0.761)^2}{15.2} \\ &= 1.714 \text{ m} \end{aligned}$$

Comparing actual head with the required head, drawdown for Q'' is obtained as $1.714 - 1.707 = 0.007 \text{ m}$.

For $Q''' = \frac{2}{3} (\sqrt{\frac{2}{3} g}) C_f B_2 H'''^{1.5} = 16.729 \text{ m}^3/\text{s}$

$$\therefore H'''^{1.5} = \frac{16.729}{1.705 \times 5.913} = 1.659$$

$\therefore H'''$, that is, head required = 1.402 m

$$\begin{aligned} \text{Actual head on sill} &= d'''_1 - Z + h'''_v = 1.524 - 0.153 + \frac{(0.686)^2}{15.2} \\ &= 1.402 \text{ m} \end{aligned}$$

Comparing actual head with the required head afflux for Q''' is obtained as $1.402 - 1.402 = 0.000 \text{ m}$. Since the drawdown and afflux are negligible, the height of hump and width of throat as estimated above are considered satisfactory.

c) Length of Throat

Referring to 6.2,

$$L_2 = 2.5/H = 2.5 \times 2.961 \text{ m} = 7.403 \text{ m}$$

d) Inlet Transition

Referring to 6.1.1,

$$\text{Radius of side walls} = 3.6 H^{1.5} = 3.6 \times 2.961^{1.5} = 18.338 \text{ m}$$

This curvature is to be continued till it subtends an angle of 60° . Further, onwards, it should be continued tangentially to meet the sides of the channel upstream. In the present case, however, the curved walls meet the sides of channel when it subtends an angle of 50° . It is, therefore, not necessary to continue the walls further (see Fig. 5).

The length of inlet transition may now be found out knowing B_1 , B_2 and the radius of bell mouth entrance R using the relation

$$L_1 = \sqrt{\left(2R - \frac{B_1 - B_2}{2}\right) \left(\frac{B_1 - B_2}{2}\right)} = 12.192 \text{ m}$$

$$\therefore \text{Radius of curvature of hump } r_h = \frac{L_1^2 + Z^2}{2Z}$$

$$= \frac{(12.192)^2 + (0.153)^2}{2 \times 0.153} = 485.844 \text{ m}$$

The total head is much more as compared to the hump height and hence the curvature is too flat according to 6.1. The hump should, therefore, be joined by a straight line to the channel bed on the upstream as specified in 6.1.

e) *Design of Baffle Platform* — The design of baffle platform is made according to 6.5, which gives the design of parallel sided fall. The fall proposed is, however, with the expanding sides. It is, therefore, necessary to convert the fall in the water level ΔZ_e with the expanding sides into ΔZ_p , which would be the fall in the water level in parallel side fall, by using equation

$$\Delta Z_e = \frac{\Delta Z_p}{K^{0.152}}$$

$$\text{wherein } K = \text{fluming ratio} = \frac{B_2}{B_1} = 0.3881$$

$$\therefore \text{Fall in water levels with parallel sides} = \Delta Z_p$$

$$= 1.829 \times 0.3881^{0.152} = 1.585$$

$$\therefore \text{Downstream water level with parallel sided fall}$$

$$= \text{Upstream bed level} + d_1 - \Delta Z_p = 30.480 + 3.048 - 1.585 = 31.943$$

Assuming the level of baffle platform is 28.346 m,

$$\Delta Z = (\text{which is the difference of level in the crest and the level of baffle platform}) = \text{bed level of upstream channel} + Z - \text{level of baffle platform}$$

$$= 30.480 + 0.153 - 28.346 = 2.287 \text{ m.}$$

$$\text{Solving the equation (7), } d_s = 0.945 \text{ m}$$

$$\text{Substituting this value of } d_s \text{ in equation (6), } d_s = 3.589 \text{ m}$$

$$\therefore \text{Level of baffle platform required} = \text{Downstream water level with parallel sided fall} - d_s = 31.943 - 3.589 = 28.354 \text{ m}$$

Comparing the assumed level of baffle platform with the required level of baffle platform the difference is obtained as

$$28.354 - 28.346 = 0.009 \text{ m}$$

which is negligible.

$$\text{Actual water level on the downstream with expanding sides is}$$

$$\text{obtained as u/s WL} - \text{fall} = \text{upstream bed level} + d_1 - \Delta Z_e$$

$$= 30.480 + 3.048 - 1.829 = 31.699 \text{ m.}$$

Since the fall is with the expanding sides, actual downstream depth above baffle platform $= d_4 = \text{downstream WL} - \text{level of baffle platform} = 31.699 - 28.346 = 3.353 \text{ m}$.

Using equation (9) the required depth of water above baffle platform for falls with expanding sides $= d_4 = \Delta Z_p + d_s - \Delta Z_c$
 $= 1.585 + 3.589 - 1.829 = 3.345 \text{ m}$.

Comparing the actual depth with the required depth, the difference is $3.353 - 3.345 = 0.008 \text{ m}$.

The estimated value of d_4 is in close conformity with actual value of d_4 , hence the level of baffle platform is considered satisfactory.

f) Design of Baffle Wall

Referring to 6.5, height of baffle $h_b = 1.5 (D_c - d_s)$

$$\therefore D_c = \left(\frac{q^2}{g} \right)^{\frac{1}{3}} = \left[\left(\frac{51.352}{5.913} \right)^{\frac{2}{3}} \right]^{\frac{1}{3}} = 1.973 \text{ m}$$

$$\therefore h_b = 1.5 (1.973 - 0.945) = 1.542 \text{ m}$$

$$\text{Distance of baffle from the toe of glacis} = L_b = 5.25 h_b \\ = 5.25 \times 1.542 = 8.095 \text{ m}$$

The upstream face of baffle wall should be curved with radius equal to and ending at $\frac{2}{3}$ of $h_b = \frac{2}{3} \times 1.542 = 1.028 \text{ m}$

$$\therefore \text{Top width of baffle } h_b - \frac{2}{3} h_b = \frac{1}{3} h_b = 0.514 \text{ m}$$

$$\therefore \text{Bottom width of baffle wall} = 0.514 + 1.028 = 1.542 \text{ m}$$

g) Design of Glacis — Following 6.4, the radius of curve connecting the throat and glacis $= 2H = 2 \times 2.961 = 5.922 \text{ m}$

Slope of glacis $= 2 : 1$

The radius of curve connecting glacis and baffle platform $= 2.961 \text{ m}$

$$\text{Projected horizontal length of glacis} = L_s = 0.69 H + 2 \Delta Z \\ = 0.69 \times 2.961 + 2 \times 2.287 = 6.617 \text{ m}$$

h) Design of Cistern

Referring to 6.7 and assuming shingle bed, the length of cistern $= L = 6 d_s = 6 \times 3.048 = 18.288 \text{ m}$

$$\text{The depth of cistern at the sides} = 1.40 d_s = 1.4 \times 3.048 \\ = 4.267 \text{ m}$$

$$\text{The depth of cistern at the centre line} = 1.75 d_s \\ = 1.750 \times 3.048 = 5.334 \text{ m}$$

j) *Expansion* — Since this is a fall with expanding sides the walls of the cistern would be curved in plan to give hyperbolic expansion using equation

$$\frac{B_0 B_s L}{LB_s - (B_s - B_0)T}$$

Width at the toe of glacis = $B_0 = 5.913$ m

$$\begin{aligned} \text{Width at } 1 d_s, B_{v_1} &= \frac{5.913 \times 15.240 \times 18.288}{18.288 \times 15.240 - (15.24 - 5.913) 3.048} \\ &= 6.585 \text{ m} \end{aligned}$$

$$\text{Width at } 2 d_s, B_{v_2} = \frac{1\ 648.007}{278.709 - 9.327 \times 6.096} = 7.428 \text{ m}$$

$$\text{Width at } 3 d_s, B_{v_3} = \frac{1\ 648.007}{278.709 - 9.327 \times 9.144} = 8.520 \text{ m}$$

$$\text{Width at } 4 d_s, B_{v_4} = \frac{1\ 648.007}{278.709 - 9.327 \times 12.200} = 9.988 \text{ m}$$

$$\text{Width at } 5 d_s, B_{v_5} = \frac{1\ 648.007}{278.709 - 9.327 \times 15.240} = 12.068 \text{ m}$$

$$\text{Width at } 6 d_s, B_{v_6} = B_s = \frac{1\ 648.007}{278.709 - 9.327 \times 18.288} = 15.240 \text{ m}$$

k) *Design of Deflector*

According to 6.8,

$$\begin{aligned} \text{Height of deflector} &= \frac{1.75 d_s}{12} = H_d \\ &= \frac{1.75 \times 3.048}{12} = 0.445 \text{ m} \end{aligned}$$

$$\text{Length of deflector} = 4 H_d = 1.780 \text{ m}$$

$$\text{Breadth of deflector} = H_d = 0.445 \text{ m}$$

$$\text{Gaps in deflector} = \text{distance between the two rows} = H_d = 0.445 \text{ m.}$$

Figure 5 illustrates this.

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